such as the ones described here, and can do so without great difficulty with various school abilities.

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PHOSPHATE DEPOSITS IN THE MISSISSIPPIAN ROCKS OF NORTHERN UTAH

SINCE 1908 extensive work has been done both by private individuals and the U. S. Geological Survey to determine the amount and character of the rock phosphate in the Rocky Mountain region. The principal work of the investigation of the deposits, however, has been confined to the well-known horizon in the rocks of upper Pennsylvania of Permian age. It is now known that phosphate exists in the Mississippian rocks in a zone more than 2,000 feet stratigraphically below the phosphate horizon that has heretofore been given so much study.

The zone containing the phosphate is more than 100 feet thick and consists of layers of phosphate and black and brown shale with interstratified layers of sandy limestone. In extent it is known to outcrop in a north-south direction for more than forty miles, and sections studied show it to have an area of more than one hundred square miles. It has been reported as far south as Ogden Canyon[1] but no detailed section has been measured in that locality.

On the east side of Cache Valley the phosphate rocks have been prospected for coal and this exposure has given the best opportunity for detailed study. The face of the mountains which form the eastern boundary of the valley is a weathered fault scarp which terminates the western limb of a syncline. The ledges on the face of the mountain are exceptionally well exposed, the rock being principally bluish gray limestones with thin beds of shale and quartzite. Here the geologic section is well exposed and shows Silurian rocks at the base and Pennsylvanian at the top of the succession. Only the lower members of the Pennsylvanian or Permian are present in this locality.

1 Blackwelder, U. S. Geol. Survey Bull., 430.

Observations on the face of the mountains, which extend more than 4,000 feet above the valley, show that the rocks strike N. 10° to 14° E., and dip eastward from 20° to 30°. The beds flatten to the eastward and about six miles east of the face they rise again, the strata on the eastern limb of the syncline dipping as much as 10° to the west. Erosion has clearly exposed the higher beds on the eastern limb of the syncline.[2] The phosphate rock is exposed on both the east and west limbs of the syncline which lies near the top of the range.

The Logan River has cut through the range from east to west, and has made a good exposure of all the strata included in the upper part of the synclinal fold. The phosphate zone, therefore, lies in two separate areas, one to the north and one to the south of the river. The Mississippian rocks are well up on the western side of the mountains forming the eastern boundary of Cache Valley and even in the lowest part of the fold in the canyon they are more than 1,000 feet above the river.

The zone containing the phosphate is exposed in a cliff of very compact bluish gray limestone which is usually more than a hundred feet thick and contains an abundance of cup corals. At the base of this cliff there is a lean phosphatic zone from five to seven feet thick of shale containing a few bands of chert. The shale also contains several thin layers of oolitic rock phosphate ranging from one half to one inch in thickness. One sample taken from all of these layers yielded only 7.21 per cent. tricalcium phosphate. This zone is probably of no economic value. It has been prospected in a number of places for coal.

The thicker and richer phosphate zone lies just above the thick ledge of limestone. The phosphate rocks are less resistant to erosion than the underlying and overlying limestone ledges and the latter stand out more prominently than the included softer beds. The rocks in the phosphate zone which are generally dark colored contain thin bands of non-phosphatic limestone with shale and some

2 See Geological Map—parts of western Wyoming, southeastern Idaho and northeastern Utah—Hayden survey, 1877.

chert. Measurements of some of the beds were taken in Providence Canyon and are shown in the table below.

At the top of the phosphate zone the rocks are not sufficiently well exposed to afford detailed study. A tunnel driven near the upper limestone ledge shows a few inches of good rock phosphate interstratified with dark-colored limestone and shale.

Thirty feet below this ledge twenty inches of oolitic phosphate rock was measured and a sample (No. 1) yielded 55 per cent. $Ca_3(PO_4)_2$. In the next thirty feet below there are thin bands of oolitic phosphate but none of them are believed to be thick enough to be of economic value. The details of the lower part of the bed in Providence Canyon follow:

No.	Kind of Work	Per Cent $Ca_2(PO)_3$
	3 feet dark gray limestone	
2	18 inches phosphatic shale	30.10
3	12 inches shaly phosphate rock	16.71
4	48 inches dark shaly phosphate rock...	65.43
	24 inches gray limestone	
5	48 inches shale, some layers phosphatic.	14
6	11 inches black shale	8.41
7	30 inches shale, oolitic phosphate, in bands	21.30
	24 inches sandy limestone	
9	38 inches phosphate rock, shaly	33.01
	18 inches chert	
	12 inches black shale	
10	30 inches phosphate rock	35.83
11	12 inches phosphate rock	46.34
	2 inches black chert	
12	48 inches black shale	3.91
	6 inches black chert	
13	21 inches black oolitic phosphate rock..	65.76
	1 inch black chert	
14	12 inches black shaly phosphate rock..	21.40
15	18 inches brown oolitic phosphate rock.	68.59
	bedding planes	28.31
	6 inches shale	
16	6 inches shale showing phosphate in	
	2 inches chert	
17	4 inches shaly phosphate rock	27.12
	20 inches sandy limestone	
18	18 inches brown oolitic phosphate rock.	66.9
	12 inches black shale	
	16 inches black shale with bands of chert, ...	
	5 inches brown oolitic phosphate rock.	52.22
	7 inches shale	
	2 inches oolitic phosphate rock with much hematite	
	Limestone ledge	

The samples for analysis were taken only two or three feet under the surface and it seems quite probable that they have been considerably leached for the rock is less firm and crumbles more easily than that from the upper Pennsylvanian or Permian horizon. No sampling has been done below the level to which roots penetrate. It is thought the amount of phosphate may decrease to some extent with depth, owing to the leaching of the less soluble constituents and the concentration of the phosphoric acid in the leached zone.

One very noticeable feature in the phosphate zone in this locality, which is an aid in tracing the phosphate, is that usually the growth of vegetation is denser along the line of outcrop than elsewhere. On hillsides which face the south and, therefore, have but little moisture or vegetation, growths of wild cherry, maple, and aspen extend along the outcrop. As a few small seeps and springs issue from the phosphate shales the denser vegetation there should perhaps be partly accounted for by the moisture.

At a place four miles north of the locality in Providence Canyon where the samples mentioned were obtained, two other samples were taken from separate layers of oolitic phosphate rock near the lower part of the deposit. The sample from one bed 18 inches thick yielded 55.21 per cent. tricalcium phosphate.[3] The other sample from a bed 42 inches thick yielded 61.32 per cent. of the material. The section does not seem to agree in detail with the measurements made in Providence Canyon. It is thought by the writer that the Mississippian rocks are sufficiently rich in tricalcium phosphate to warrant investigation as to their economic value.

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[3] The analyses were mostly made by Mr. C. T. Hirst in the Experiment Station chemical laboratory.